A Planar Dielectric-Filled-Parabola-Feed Frequency Multiplier

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Summary **In this paper, we present a novel quasi-optical all-planar frequency doubler th at could provide an alt ernati ve approa ch to conventional waveguide circuits for millimeter- and submillim eter-wave signal generation. By utilizing a quad-bridge-diode configuration, we us-c able to isolate the input and the output circuits without the use of complicated filter structures. Two pairs of polarizat ion switched double-slot antennas directly couple input and output signals to the diodes and substitute for the hybrids commonly required in balanced circuits. The integrated quad-brid~c-diode / slot-antenna circuit ca n then be mounted on u didcc[ric-filled parabola for coupling to quasi-optical propagation systems. Measurements on a X to K-band doubler show frequency conversion loss of 6.8 dB at the output frequency of 20.3 GHz.**

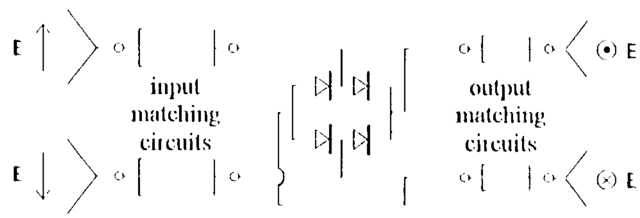
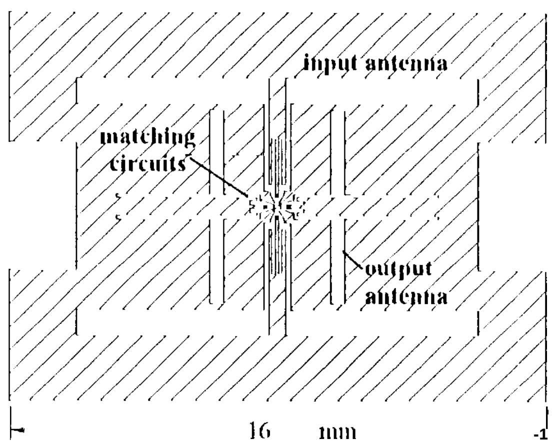


Figure 1 Quad-diode frequency doubler configuration. The two pails of antennas deliver to, and extr act from, the diodes, an equal amount of the power but with opposite polar ity. 1 Because of the built-in even harmonic rejection, no filtering is required to separate input and output frequencies.



Figu re 2 X/K-band par abola feed layout. The circuit is fabr icated on a thin quar tz substrate but mounted on a stycast(ϵ_r= 3.9)-filled parabola to satisfy the! infinite-thickness dielectric substrate condition. A commercially available diode chip (X-1 Band Mixer Quad, model DMJ2088 by Alpha Industries) is bonded to the tips 01 the coplanar waveguide center lines shown as clots, 1 Because of the symmetry, the input and the output circuits are fully isolated.

I. Introduction

Receiver components in the ESA/NASA Far Infrared and Submillimeter Spare Telescope & Submillimeter Intermediate Mission (FIRST/SMIM) require submillimeter wave local oscillator sources with an output power of 50 to IO(J microwatts in the '1'117, frequency range in order to carry out submillimeter astloplq'sits from space. Whisker-co]lhc[ccl diode multipliers in the millimeter-wave bands have been space qualified for several missions and recently demon strated in the laboratory a 1 frequencies as high as 1 "1'1 Iz [1]. 1 lowever, these waveguide based multipliers involve an extremely labor intensive and low-yield assembly process, and the limitations inherent in the device geometry makes implementing multi-diode bala need circuits impossible. With the advent of high quality submillimeter -wave planar diode technology, however, multi-diode circuit fabrication becomes realizable. Multipliers and mixers utilizing planar diodes have been demonstrated to have better performance than similar whisker contacted str uctures up to 200 GHz [2,3]. In this paper, we introduce a new appr oach where the planar doubler circuit utilizes a fully open antenna architecture and combines device and circuit symmetr ics to yield an ext remely simple and compact design with inherent port-to-port isolation.

11. Design

Our frequency multiplier design replaces the waveguide circuit with an all -planar, much more readily scaled, monolithically fabr icated, open-structu re circuit with quasi-optical coupli ng to fr ee space. The circuit itself utilizes a quad-bridge diode configuration for second-harmonic signal generation with built-in frequency isolation (Figure 1, a similar circuit geometry was independently p rop osed in [4]). Compar ed to single diode multipliers, this configuration maintains the same conversion efficiency with the same optimum input ant] output load impedances, but quadruples (IIC power handling capability.

More importantly, the quad-bridge diode circuit provides effective isolation betwee n the two input and the two output antenna s with its inher ent even harmonic rejection at the input and odd harmonic rejection at the output, thus eliminating the need for complicated filter structures. The quad array only requires simple matching circuits at the fundamental input and the second harmonic output frequencies.

The circuit configuration shown in Figure 1 is implemented on a parabola feed with two pairs of slot antennas, eacl i with its own coplanar-wa veguide matching circuits. Input and output coupl ings are accomplished by placing the feed ci cuit on an electrically thick substrate lens (a dielecti ic-filled pai abola in this instance). The t w i n slot antennas provide excellent input/output beam characteristics [5] with the beam profile set by the slot length and separation and the waist diametei (f-number) adjusted by varying the parabola aperture size. For the X/K-band feed circuit on a thick quartz substrate, the input and output slot antennas are chosen to be $0.4\lambda_0$ long and $0.24\lambda_0$ apai t at 10 and 20 GHz, respectively. The slot-width of the input antennas and the gap-width between the ground planes for the coplana i transmission lines are fixed at 0.8 mm while the output slot-width is 0.4 mm. In between the diodes and the slot antenn as, coplanai transmission-line matching circuits are inserted to transform the slot antenna impedances to the desired optimum input and output load impedances for the d i o d e . s . Because the distance between antennas and the diodes are fixed, coupled transmission lines, along with low and high impedance sections, are used to control phase delays in the matching circuits. In older not 10 excite slot line modes, the symmetry in the matching circuit is preserved and all the ground plain for the matching circuits are shorted together at the centei of the coplanar waveguide cross-junction underneath where the diodes aic placed

The overall size of the feed circuit is minimized to reduce the parabola beam blockage loss. The small feed size also allows us 10 simulate the diode de-embedding impedances for the whole feed sti ucture on top of infinitely thick quai tz substrate using HP-MDS. With the input power of 1?. dBm, MDS also predicts the conversion loss (which is taken as the ratio of the power transmitted from the ou tput antennas to the powei coupled into the input antennas) to be 6 dB al the output frequency of 20 GHz for the unbiased mixer-quad diodes (Manufacturer's equivalent circuit model for a typical DMJ2088 X-Band Quad contains R_s Of 6 o11111s, C_{j0} of 76 fF, and $C_{parasitic}$ of 35 fF). Mixei -quad is used because a suitable varactor diode package is not commercially available. Even though reverse-biasing the mixer diodes slightly improves the conversion efficiency, no dc bias circuitry has been incorporated in this particular design to keep the *circuit geometry simple*.

III. Measurement

The planar feed circuit (Figure 2) is fabricated on a 10-mil thick quai tz substrate and glued down 1o the top of a sty cast-filled pal abola (cl" = 3.9) as sl iown in Figure 3. The radius o f the parabola is 4.1 inches (3.47 λ_0, at 10 GHz) and the focal length is 2.1 inches. A wire grid polai izei is used to through couple the input signal and reflect the output beam to the receiver at 90 degrees 10 the optical axis of the parabola. The conversion loss measurements are performed by focusing and collecting the Gaussian beam into and from the parabola with two 11 -inch diameter PMMA lenses and standard gain horns for the X-band (i nput) and the K-band (output). Calibration measurements pei formed on the measurement system with the focal plane

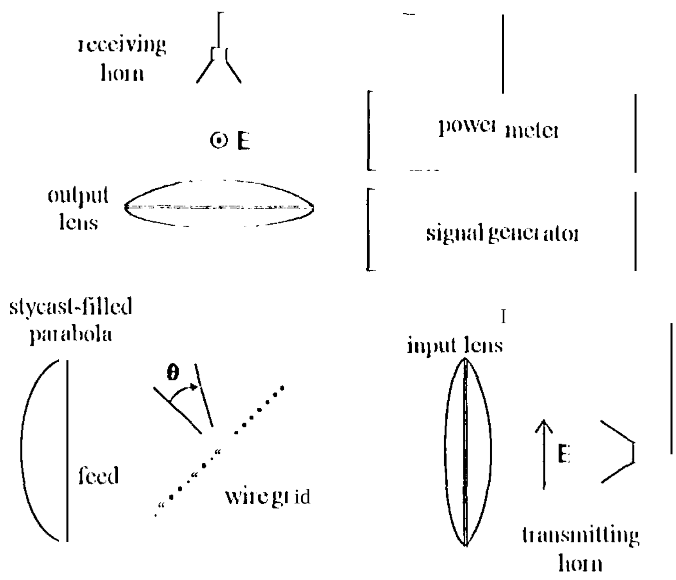


Figure 3 The measui ement setup for the X/K-band planai frequency doubler. Two lens-coupled standard gain hoi i is ai e used to eliminate the diffiaction losses in the system. The wile gi id i eflects the output signal to separate it from the nput. By rotating the gi id and removing the output lens, the output beam pattei n can be m easui ed.

of the pai abola replaced by a mirror indicate the input path loss between the input f e e d horn and the parabola (including the diffraction and the lens dielectric 1o sscs) to be 2,5 dB at 10 GHz, and the output path loss to be 2,5 dB at 20 GHz. Another *calibration measurement, this time with the parabola* f e e d replaced by a **m e t a l** short, confirm the stycast dielectic **l o s s** tangent to be 0.01 and the loss to be 2,3 dB at 10 GHz and 4.6 dB at 20 GHz assuming the maximum deliverable power i s reaching the pai abola feed. Additional back radiat ion loss for the parabola feed of 0.5dB and Gaussian beam mismatch loss of 0.3 dB are also calculated from the theory. After compensating for the system losses (5.6 dB at the input and 7.9 dB at the output), a best conversion loss of 6.8 dB was measured at the output frequency or 20.3 GHz. We are unable to remove all the mismatches in the o p t i c a l system, and the frequency sweep measurements (Figure 4a) contain large resonances. The power sweep measurement (Figure 4b) cai ried out a t 20.3 GHz indicates the diodes reach saturation when the power received by t h e input slot antennas is about 1 2 dBm. The output radiation patterns from the p a r a b o l a are also examined by rotating the polarizei grid without the output lens. The measured E and H plane patterns a g r e e well with the theory down to -10 dB and show the 10-dB beamwidth of 10 degrees for the H-plane and 7 degrees for the E-plane.

IV. Conclusion

We have hilt and measureed an X to K-Band qoasi-optics] frequency multipliei to test the feasibility of similar circuits at millimetei-wave frequencies. The perfomance of the clo ub lc r circuit has been compared with the simulation results from MDS with good agreement. A 320/640 Ghz version using a silicon parabola is now being tested

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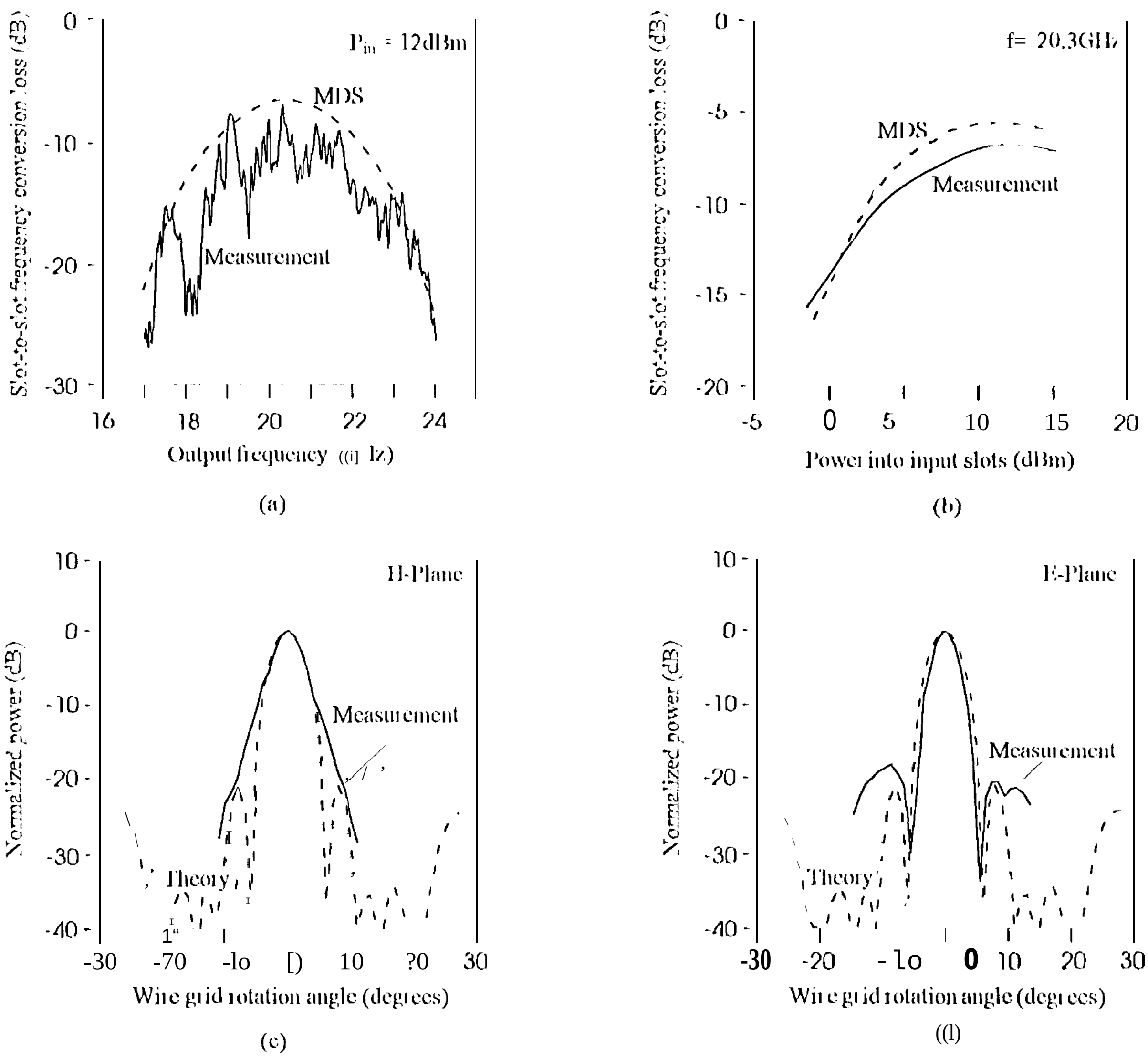

Figure 4 Measurement results. (a) slot-to-slot frequency conversion loss vs. output frequency with input power of 12 dBm, (b) conversion loss vs. input power into the input slot antennas at 20.3 GHz, (c) H-plane and (d) E-plane output power radiation pattern of the parabola. Dashed lines show HP-MDS simulation results (a, b) and the theoretical pattern calculated for the parabola without the back-side radiation (c, d).